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# The Nature of Matter

## Conceptions and Applications of the Atomic Theory

By EDWARD M. SCHOENBORN, '31

### *Early Speculations*

To find the earliest speculations on the construction of matter which are known to history and which have an authentic value, we must go back several thousand years before Christ to the early Greek philosophers. They entertained two hypotheses in strong contrast with each other, only one of which could be true. One proposition states that matter is infinitely divisible and continuous—the smallest conceivable body yet consisting of an infinite number of parts. This philosophy was held by Anaxagoras (4th century B. C.) and possibly by Aristotle. The second states that all matter is composed of an assemblage of parts incapable of further division. The germ of this theory though attributed to Leucippus, Democritus and Epicurus (3rd and 4th centuries B. C.) was developed to the greatest extent by Lucretius, in whose wonderful poem, "De Rerum Natura," we consider the first views concerning the nature of matter to have been born.

### *Lucretius*

The thoughts of Lucretius evince a great likeness to our present conception of the nature of matter. He says that since nothing is born of nothing (the foundation of his philosophy) and nothing perishes, all things resolve into their primordial bodies. He describes his "atoms" as hard, invisible bodies constantly moving in an omnipresent void, and incapable of further division. To account for the various physical properties of substances he assigns to atoms what seems akin to free will. Moreover, he gives detailed proof of their existence and displays unique insight into their forms and motions; which seems all the more wonderful when we remember that he could rely on no experience or experimental evidence but on the simple powers of his reasoning alone.

### *Transition*

Until the birth of modern chemistry, experimental science thrived only with the alchemists, and with the exception of the work of the monks who alone are responsible for the preservation and advancement of learning during the middle ages, little was accomplished in the way of discovery. Modern chemistry began with the work of Lavoisier and Priestley. From then on rapid

advances were made; new elements discovered; the composition of water determined; new compounds analyzed. And the advent of John Dalton's theory elucidated many forces in the chemical as well as the physical realms of science.

### *The Atomic Theory*

Being but secondarily interested in chemistry, this humble school master noted, with the skill of an analytical mind, the mathematical harmony existing between the four laws of chemical combination. Eager to explain them, he saw fit to do so in only one way. So in 1806 he revived the old conception of atoms and gave to the thought an impetus which has been increasingly felt to

the present day. His explanation of these laws was exceedingly simple; "All elementary matter is made up of minute bodies called atoms. The atoms of each element are all alike in average masses. When elements react with each other, the action takes place between the different kinds of atoms and in definite numerical ratios." (McPherson and Henderson: A Course in General Chemistry, Chap. VII, page 99). We are now able to understand these laws for we have definite units with which to work. That substances unite in the ratio of whole numbers, and that compounds

Most of us remember Chemistry 412 as one of the most fascinating courses in our college curriculum. It gave many of us our first conception of the nature of matter.

This year Dr. W. L. Evans conducted a very interesting "educational experiment," he gave his students the opportunity of writing up their knowledge at the close of the course. Each student set about the task as tho he were an original investigator publishing the results of research.

The work included in this article covers the following lectures: (1) The Periodic Law and Dalton's Atomic Theory, by Dr. Day, Division of General Chemistry; (2) The Discovery of Radium; (3) Isotopes; (4) Atomic Structure by Dr. Evans; (5) Evidence for the Existence of Molecules, by Dr. Mack, Department of Physical Chemistry; (6) Non-geometrical masses of Molecules (Colloids) by Dr. Day; (7) Geometrical masses of Molecules (Crystals) by Dr. McCaughey, Department of Mineralogy; (8) Matter and Energy by Dr. Smith, Department of Physics.

This article by Mr. Schoenborn was picked as the best student thesis in composition and in the facts presented. It will prove interesting reading.

—Editor.

always have a definite composition could now be accounted for by the fact that atoms of each element have a definite mass. And numbers could now be assigned to the elements that would indicate the relative weight of the atoms themselves. Atomic weights have been accurately determined and form a solid mathematical basis for all work involving atoms and molecules.

### *Prout's Hypothesis*

In view of the fact that most all of the atomic weights then known were approximately whole numbers and that hydrogen was near unity, Prout suggested that all elements are multiples of hydrogen. This seemed quite plausible indeed until it was conclusively shown that many of the elements do not have whole number atomic weights but fractional ones instead. Thus, chlorine has an atomic weight of 35.46; magnesium, 24.36, and so on. Naturally, the hypothesis was soon abandoned; but not until it had stimulated a great

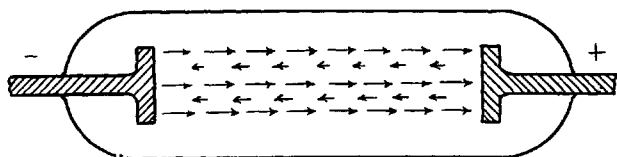


Fig. 1. Diagram of Cathode Tube. The longer arrows indicate the direction in which electrons move from the cathode, the shorter ones indicate the movement of the positive ions toward the cathode.

amount of thought and much valuable research, especially in the accurate determination of relative atomic weights.

#### *Attempts at Classification*

As new elements were discovered and their atomic weights more accurately determined, various similarities were found to exist between the properties of certain elements. As the atomic weight was at that time considered the most characteristic property of the element, many plans of classification were suggested with the atomic weight as a basis. Dobereiner showed, in 1829, that groups of three elements, having somewhat similar properties, could be arranged so that the atomic weight of one would be an arithmetical mean between the other two. Thus, bromine with atomic weight of 79.916 is a mean between chlorine (35.457) and iodine 126.932; and zinc of atomic weight 65.38 is a mean (approximately) between magnesium (24.32) and cadmium (112.41). Newlands found that in the order of increasing atomic weights, beginning with helium, every eighth element would fall into a group having very like chemical, and sometimes physical, properties. For instance, the second, tenth, and eighteenth elements (helium, neon and argon) fall into a group called the "rare" gases whose decided inactivity stand out quite prominently. This theory became known as the "Law of Octaves."

#### *The Periodic Law*

This same attempt at systematic classification led, in 1869, to an innovation known as the Periodic Law. It is attributed quite independently to two men—Mendeleeff and Meyer. They showed that elements arranged in order of the atomic weights may be divided into groups such that a similar gradation of properties from one element to another occurs as a periodic function of their atomic weights. The elements fall into eight groups arranged in vertical columns of twelve horizontal series or periods according as they form oxides or hydrides as indicated by a general formula given at the head of each group. Thus, the elements of each group are found to resemble each other not only in chemical and physical properties, but also in their having a common positive or negative group valence.

#### *Irregularities in the Table*

While the table is a very orderly arrangement many irregularities may be noted. Hydrogen is noticeably absent, as is the group of the rare earth metals between lanthanum and hafnium. While the properties of gold, silver, and copper are quite incongruous they are, nevertheless, placed

in the same group. Especially noticeable, also, is the fact that there is no regular gradation between successive weights, and that in three cases (argon and potassium, tellurium and iodine, cobalt and nickel) the order is even reversed. We shall find, however, that recent discoveries have given a somewhat different interpretation to the periodic law, from that of Mendeleeff, so that many of the apparent discrepancies in the table can be well accounted for, and the arrangement is more orderly than it seems.

#### *Evidence for Existence of Atoms and Molecules*

Up to this point we have dealt mostly with the historical issues that have led up to our modern conceptions of atoms and molecules. While we have spoken of them quite promiscuously in theory, yet we have endeavored no proof of their real existence or their practical application to the nature of matter. Let us look at these primordial bodies themselves and see how the atomic theory is now a proven fact.

#### *Size*

We ask first of all: How small are these atoms and molecules? And we answer that they are so small we can never hope to see them except in a very indirect way. The smallest particle that one can see, even with the most powerful microscope, must be within the range of the wavelength of light; and the diameter of such a particle has been calculated to be about .00001 cm. But by reason of X-rays, whose wavelengths are the shortest known, it has been calculated that the diameters of atoms and molecules are around .00000001 cm. and .0000001 cm. It is said that fifty trillions of atoms can crowd together on the head of a pin.

#### *Kinetic-Molecular Theory*

We have definite proof that atoms and molecules exist and we may mention primarily the Kinetic-molecular Theory of Gases. Gases are made up of molecules in rapid motion and whose distances apart are relatively large in comparison to their diameters. We know that temperature and pressure govern their activity and the pressure they exert in a given volume according to the various gas laws of Boyle, Charles, and Gay-Lussac. The facts of diffusion and odor can hardly be accounted for in any other way than by the existence and motions of molecules. It was from these

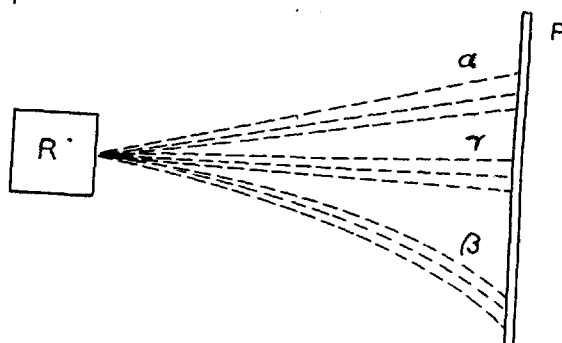


Fig. 2. Diagram representing the deflection of rays of a piece of radium (R). By noting the deflection as recorded on the photographic plate (P), the relative masses and charges of the particles have been calculated.

laws that Avogadro developed his famous hypothesis and today we have avogadro's number, a fundamental standard for mathematical calculations in both physics and chemistry. Knowing the weight of 22.4 liters of a gas and that this volume contains  $6.062 \times 10^{23}$  molecules, it is simple mathematically to determine the actual weight of one molecule.

### Radiometer

We have further proof in the delicate motions in the radiometer, and have little thought that molecules did all the work. It is an established principle of physics that dark objects absorb greater amounts of energy than do light ones. It will be noted that movement of the vanes occurs only in the presence of light rays. Now, while these vanes revolve in a partial vacuum, there are, nevertheless, millions of molecules constantly bombarding their sides, one of which is dark, the other polished. In consequence of these facts, as the molecules hit the dark sides of the vane they receive a greater amount of energy than do those that strike the opposite side, and so in rebounding the recoil tends to move these arms in much the same manner as a gun recoils when a shot is fired. This is actually what happens, for the polished surfaces move toward the source of energy and the dark surfaces are pushed away from it.

### Oil Films

Another interesting experiment has to do with a more complex sort of molecule. If we should dust the surface of some water in a large, shallow vessel with some light powder such as talc, and place in the center a very small drop of oil such as olive oil or paraffine, or better, oleic acid, immediately an oil film will distend over the whole surface, pushing the powder to the edge of the vessel. It appears that a drop of this oil, consists of long molecules, each of which has a part that is soluble in water, the rest and greater portion being insoluble. Now, when this drop is placed on the water, each molecule hastens to root itself by its active end and stands upright. Soon all range themselves side by side over the surface. Thus, a thin film one molecule thick covers the water. If the weight of the drop of oil is known and the surface area measured, the thickness of the film may be calculated. And this has actually been done by such men as Rayleigh, Devaux, Langmuir, Hardy and Adam, in their work with these long-chain molecules.

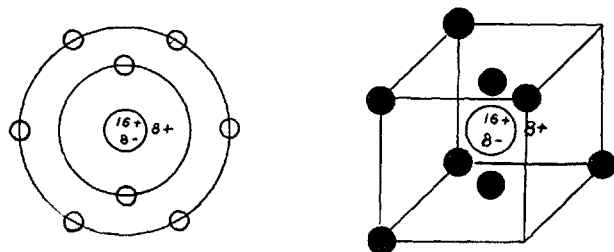


Fig. 3. The Bohr and Rutherford Atom. Here are shown the two conceptions of an atom of oxygen. The nucleus containing sixteen protons (+) and eight binding electrons (—) has a nominal charge of eight protons (+). These charges are evenly balanced by the eight satellite electrons definitely revolving about the nucleus.

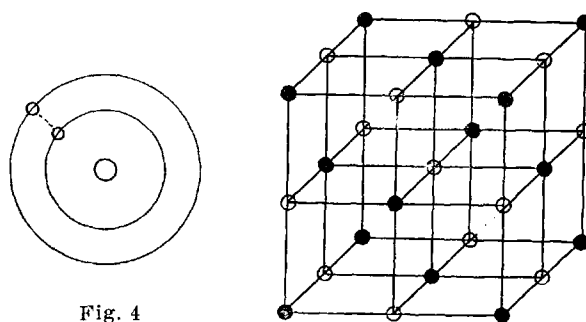


Fig. 4

Fig. 4. The single electron of the hydrogen atom on falling to a lower energy level gives off, in the form of radiation .008 grams of energy.

Fig. 5. A Sodium Chloride Crystal. Atoms, or ions, of sodium (white) and chlorine (black) are symmetrically arranged on the vertices of a "space lattice" as shown.

### Colloids

From the nature of colloids we may advance yet further proof for the existence of molecules. A colloidal system is made up of very minute particles ranging in size from 1 to 200 millimicrons suspended in a liquid. They are made up of thousands of molecules but are yet invisible to the eye even with the aid of a powerful microscope. If, however, a strong beam of light is passed through the suspension and we look at it through a microscope at right angles to the beam, we shall discover that the light is diffracted by these solid particles, and the particles can be seen as bright specks in rapid motion, like notes in a beam of sunlight. The path of light is known as the "Tyndall Effect;" and the curious zigzag which they exhibit as the "Brownian Movement." We explain this motion to be a result of the kinetic energy of the molecules in the solution, which, because of their extremely high speed, will collide with the still smaller particles and thus impart to them much of the erratic motion that they themselves have. It must not be supposed that we can have only a liquid as a dispersing phase, since any substance may be colloidal and the dispersing phase will vary accordingly. Thus, included in the colloidal systems are jellies, emulsions, smokes, fogs, and foams. Even a crystalloid may be obtained in a colloidal state in any liquid in which it is sparingly soluble.

### Atomic Structure

Having proved the existence of molecules, let us now turn to their inherent structure. As late as the beginning of this century we conceived of atoms in much the same way as did Lucretius, namely as hard, minute, homogeneous bodies, indivisible and immutable. While much evidence pointed to the simplicity of such a consideration, on the other hand, many phenomena tended toward a conception of internal atomic complexity. Recent discoveries have shown the latter to be a fact. The periodic table pointed to a synthetic structure as did the multiplicity of the spectral phenomena plainly point to a complex and not a simple atomic make-up. The invention, in 1800, of the spectroscopic and the evolution of a complex spectrum for the elements; the discoveries of

(Continued on Page 18)

## NATURE OF MATTER

(Continued from Page 8)

X-rays, of radioactivity and radium, and finally of the electron—all evince conclusive proof that the atoms of each element have a distinct anatomy of their own.

*The Electron*

Of these new discoveries, the last named needs first to be mentioned. In 1897 the English physicist, J. J. Thomson, found that when a high potential is passed through a simple vacuum tube containing a slight amount of some gas, a steady stream of small particles, is shot out with tremendous velocity from the cathode and at right angles to its surface; these particles he called "Electrons." (*Fig. 1*). Now since they are attracted by the anode (the positive electrode) they must consist of negative electrical charges. So far as we know, they consist of negative electricity only. It has been calculated that the mass of an electron is  $1/1845$  that of a hydrogen atom, extremely small in comparison to the mass of the atom as a whole. He also found positively charged particles moving toward the cathode. These are not emitted from the anode but are in reality crippled molecules of the gas that have been struck by fast-moving electrons. They are much larger than electrons, being quite as heavy as the atom or molecule, and are known as "ions." As the electrons continue their course through the tube, they finally strike the surface of the anode. The energy resulting from this impact is converted into radiant energy of much the same nature as light. This source of energy Roentgen found to be the X-ray.

*Radium*

The value of radium is well known. And this lies in its enormous energy content, which it is constantly giving off in the form of radiant energy. Madame Curie discovered it to be a disintegration product of uranium, and Rutherford and Soddy have further shown us much regarding its marvelous disposition. Here we have matter truly transformed into energy. The emission of three types of rays account for this singularity. The "alpha" rays consist of atoms of helium bearing two positive charges each. They have a velocity of 20,000 miles per second but cannot penetrate the thinnest sheet of paper. The "beta" rays consist of electrons and are the same as the cathode ray of the vacuum tube. The "gamma" rays are X-rays having extremely short wavelengths and penetrative powers. (*Fig. 2*).

*The Nucleus*

The nature of these rays, both from the vacuum tube and from radium, afford further proof that matter is complex, for besides the electron, we find also a positive body. Rutherford could explain of these positive bodies to counterbalance the negative charges of the electrons, since the atom as a whole is electrically neutral. This new constituent is called the "proton" and is similar to the electron in all but in having an opposite charge and the mass of the hydrogen atom. Moseley was able to show by means of the X-ray spectrometer, that

the spectrum of each element was a regularly occurring line, shifting in position steadily to the left as the atomic weight increased. He found that the atomic number of each element, that is, its numerical position in the table, depended on the wavelength of the spectral lines, and was equal to the number of excess positive charges on the nucleus of the atom. The periodic law has thus been given a new meaning; the chemical properties of the elements are a periodic function of their atomic numbers and not of their atomic weights, as Mendeleeff had supposed.

*Isotopes*

Further disintegration of radium as well as of uranium and thorium shows that a new substance is formed at the loss of each alpha and beta particle. When the helium atom is emitted, a gas remains. It is known as "radium emanation" or "radon" and has a place in the periodic table, but two below radium with atomic number 86. Successive losses of both alpha and beta particles transform radon into radium A, B, C, D, E, F, and finally into lead with atomic number 82 (Radium G). It must be noted that the loss of an electron would increase the atomic number by one, as the loss of the double charged positive helium would lower it by two. Hence, the atomic number of uranium goes no lower than 82, as might otherwise be expected. However, thorium also disintegrates into lead with a different atomic weight. The atomic weight of uranium lead should be 206 (a loss of eight helium atoms with a mass of 4) and that of thorium lead should be 208, the latter being, in the table, but two below the former, since the atomic weights of uranium and thorium are 238 and 232 respectively. But the atomic weight of lead is 207.2. Further, UX, a disintegration product of uranium, and thorium occupy the same place on the table having different atomic weights. So also, radium and thorium-X occupy the same place and they also have different atomic weights. Moreover, products of the different radioactive series often are found to have the same periodic position. How can we explain this, then, knowing that these atoms have the correct number of charges on the nucleus and an equal number of electrons to correspond to the atomic number?

In experimenting with the mass spectrum of the elements (by means of which he could determine the masses of the positive ions by their relative deflections as recorded on a photographic plate) Thomson found that neon gave two lines, one corresponding to a ray of mass 20, and another mass of 22. These varieties are known as "isotopes" of the element. Aston found that all elements whose atomic weights are whole numbers give single lines, while those with atomic weights or mixed numbers give a mixture of isotopes. Thus, chlorine of atomic weight 35.46 is a mixture of isotopes of weights 35 and 37; and magnesium of atomic weight 24.375 is a mixture of three isotopes of weights 24, 25 and 26. Hence, these radioactive substances are mixtures of isotopes and we have cleared an apparent discrepancy in the periodic table.

(Continued on Page 20)

## NATURE OF MATTER

(Continued from Page 18)

Knowing that all isotopes are whole numbers, we are once more confronted with Prout's hypothesis, only to realize that our most important element hydrogen still remains fractional in mass. Yet Rutherford has succeeded in bombarding some of the elements with radium particles to discover hydrogen as a constituent. Perhaps if we look at the inherent structure of the atom, a plausible explanation of the phenomenon will suggest itself.

For the structure of the atom two conceptions have been advanced by the physicists, Rutherford and Bohr, and the chemists, Lewis and Langmuir. (*Fig. 3*). In both conceptions mentioned, the electrons are considered to revolve about the nucleus in much the same manner as the moon revolves about the earth; however, in the Bohr atom, these satellite electrons are considered to travel on definite orbits, while in the chemists atom they are considered to occupy fixed relative positions around the nucleus. The latter is also known as the octet theory, since the electrons may be thought to occupy the corners of a cube. The simplest atom—hydrogen—contains one proton as a nucleus and one satellite electron. All other atoms contain a number of protons equal to the atomic weight, as well as a number of satellite electrons equal to their atomic numbers. The difference in charges is balanced by an equal number of binding electrons in the nucleus which are thought to unify the protons, thus making the whole electrically neutral. Now, when a satellite electron leaves its orbit or energy level and goes to a lower one (an orbit nearer the nucleus) a definite amount of energy is given off in the form of radiation. Thus do we account for spectral lines. So, if a helium atom is composed of four hydrogen (mass=1.008) atoms, a loss of 0.32 units of mass must be accounted for. Modern physicists explain this by what is known as the "packing effect," for, in condensing four hydrogen atoms to one helium atom, it is found that there is given off an amount of energy equal in value to 0.032 weight units matter. Hence, we have a transformation of matter into energy which is quite presumable, as we shall see.

*Matter and Energy*

Today, physicists have found that energy as well as matter is discontinuous. The facts of radiation have aided in establishing this concept. The ether has long been considered a medium devoid of matter and yet it is capable of transmitting energy; but as we know, energy cannot reside outside matter. In this case, energy is now thought to be propagated in small units or quanta. Thus, when an electron moves to another orbit, a unit of energy of definite frequency is emitted. (*Fig. 4*). Hence, radiation is a form of discontinuous energy. Further corroboration of this is found in the fact that the mass of an electron is not the same at rest as when in motion, but that its mass partially depends on its speed. Additional proof that matter and energy interact may be had in X-radiation or the photo-electric effect. Though such phenomena seems to contradict the

long-established wave length theory, and have not yet been fully explained, physicists are working on it constantly and are steadily making progress.

## MOLECULAR ARRANGEMENT

*Solutions*

Having discussed the structure of the atom, let us note the arrangement or non-arrangement of atoms in space which constitute the various forms of matter. On the one hand are crystals; on the other colloids, amorphous substances, gases and liquids. We have mentioned colloids and gases in previous instances and we may now turn to certain solutions.

*Ions*

The excessive physical constant effects produced in a solution containing an electrolyte have been explained by Arrhenius to be due to the dissociation of the molecules into electrically charged particles called ions. They are atoms or groups of atoms that have either gained or lost an electron (or electrons). An anion is considered positive, a cation negative. Thus, we can explain electrolysis, since the conduction of the electric current is due to the free movement of ions from one electrode to another.

*Crystals*

Proceeding to the other division, we find the perfect symmetry of matter in the form of crystals. If it were not for the particular arrangement of molecules in the diamond, it would be worth no more than graphite. The facts of cleavage and the perfect geometrical design of the faces in respect to a definite set of axes have long suggested the arrangement of molecules in various plane positions. X-rays have proven this fact conclusively. It is also from the nature of the crystal that there has been determined much knowledge concerning the nature of the molecule. Especially important have been the experiments concerning X-ray crystal diffraction where the actual distances between planes of molecules have been calculated. Laué showed that the diffraction of X-rays depends entirely on the wave-length of the ray and on the distances between these planes. A most valuable formula has been derived from these facts, and also much knowledge of value, not only to chemists and crystallographers, but to all interested in the various forms of matter. In a polar compound, such as a crystal of sodium chloride (*Fig. 5*) the formation is thought to be due to the electrostatic forces existing between ions instead of atoms. Thus it is the sodium ion and the chlorine ion which in solution are free to separate that account for the properties common to such an electrolyte. As to non-polar compounds, scientists are still in the dark; but if past successes are any criterion of future accomplishments, then a true explanation of these phenomena should not be long forthcoming.

And thus we have come to know the building blocks of the Great Architect. How men have guessed, reasoned, and experimented; how they have studied and labored throughout the ages; how their remarkable discoveries have been an

(Continued on Page 28)





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### NATURE OF MATTER

(Continued from Page 20)

"Open Sesame" to the doors that lead to the mysteries of the universe; and finally, what they have found there—all these things we have briefly surveyed. What the future holds in store for us, no man can say. The wonderful achievements, the crowning glories of this age will make but simple history tomorrow, just as the supreme events of the past are now our heritage.

Scientists have long endeavored to control the vast forces of nature; and to some extent they have succeeded. All the marvelous electrical inventions of this age that daily add to our domestic welfare, are an outcome of study and experimentation in guiding the forces of the atoms. We can readily realize the great reservoirs of energy stored up in these bits of matter. That we shall ever tap these inexhaustible supplies, time alone can tell. Perhaps the sun is but a mass of radium whose energy the earth receives and which is but a continuous transformation of matter into energy. Perhaps we shall some day transmit power on the waves of the radio. Perhaps we may even see the atom and hear its whirrings in space. Perhaps our conceptions are all wrong—but then, that is for future generations to decide.

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